

AMMRC TR 68-19

**HIGH ENERGY RATE FORMING (PNEUMATIC-
MECHANICAL) OF TYPES 200, 250, AND 300
18% NICKEL MARAGING STEEL**

Technical Report by

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October 1968

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PROCESS LABORATORY
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
WATERTOWN, MASSACHUSETTS 02172

ARMY MATERIALS AND MECHANICS RESEARCH CENTER

HIGH ENERGY RATE FORMING (PNEUMATIC-MECHANICAL) OF TYPES
200, 250, AND 300 18% NICKEL MARAGING STEEL

ABSTRACT

High energy rate forming with a pneumatic-mechanical press of types 200, 250, and 300 18% nickel maraging steels followed by heat treatment yielded optimum mechanical properties when forged to a 75% reduction at 1900 F. These properties were slightly superior to those observed for the as-received and heat-treated materials.

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INTRODUCTION

Included among the evolution of today's various High Energy Rate Forming (often referred to as HERF) equipment is the pneumatic-mechanical press. Unlike explosive forming which requires a remote work area, the pneumatic-mechanical press is normally found housed among the more conventional metal-forming equipment. The ability of the HERF process to deliver energy rapidly, thereby inducing strain rates higher than those associated with that of conventional techniques, frequently results in greater formability limits and occasionally in correspondingly increased mechanical properties. This in turn can allow the forming of more intricate shapes than those possible with the more conventional deformation techniques.

This process, as a result of displaying appreciable dollar savings in a number of applications, is currently gaining wide acceptance in the metal-working industry. Complex components can be formed to close tolerances, thereby minimizing scrap losses and subsequent machining operations. These savings are significant when one considers the ever-increasing material costs together with the spiraling costs in today's labor market. Some typical case histories are:

1. More than four pounds of \$1.70-per-pound material saved on 13,000 parts.¹
2. Eight-pound differential drive housing; a 20% material saving.²
3. Stainless steel gimbal yoke; a 72% savings in raw material.³

The purpose of the program was to generate forging data relating the effects, if any, of high speed deformation on the physical and metallurgical properties of the 18% nickel series of maraging steel.

PROCEDURE

Three types of commercially available vacuum-melted 18% nickel maraging steel (200, 250, and 300) were obtained in the form of 2-1/8-inch-diameter bar stock. The chemical composition of the material in weight percent was as follows:

Type	C	Si	Mn	S	P	Mo	Co	Ni	Ca	Al	Ti	B	Zr
200	0.020	0.03	0.07	0.008	0.005	3.29	8.22	18.17	0.05	0.11	0.18	0.004	0.008
250	.020	.05	.06	.006	.003	4.74	7.82	18.57	.05	.11	.38	.004	.015
300	.012	.05	.07	.006	.004	4.70	8.95	18.05	.05	.10	.68	.003	.009

¹High-Velocity Forged Parts Now Available on Commercial Basis. Metalworking, January 1968, p. 109.

²NOLAND, M. C. *Designing for the High Velocity Metalworking Processes*. Machine Design, August 1967, p. 163-182.

³BANGS, S. *High-Energy Forming Yields High Savings*. Precision Metal Molding, November 1966, p. 93-97.

The bar stock was machined into 2-inch-diameter, 3-inch-long billets. Two billets of each type of maraging steel were forged in a temperature range of 1400 to 2300 F at 100-degree intervals. All the billets received a 75 percent reduction (Figure 1) at temperature using a closed die (Figure 2) in conjunction with a quick-acting pneumatic-mechanical press, Dynapak Model 1220.

Fire pressures ranged from 1500 psi for the 1400 F and 1500 F forging temperatures to 1200 psi for working temperatures from 1600 F to 2100 F and 1000 psi for temperatures of 2200 F and 2300 F. The working stroke of the machine was held constant at 10-1/2 inches.

Subsequent to the deformation operation the upset disks were sectioned into halves, one half being tested in the as-formed condition and the other half receiving the following heat treatment prior to mechanical test evaluation: solution anneal at 1500 F for 1 hour; and age at 900 F for 3 hours.

TESTING

Standard tensile (0.252-inch diameter) and impact (0.394 x 0.197 inch notched face) specimens were machined from both the as-formed and as-formed-plus-heat-treated disk halves. All tests were conducted at room temperature. Each data point plotted in Figure 3 is the average value of two tests.

MECHANICAL PROPERTIES VERSUS FORGING TEMPERATURE

As-Formed

As shown in Figure 3, no significant trends were observed for working temperatures of 2100 F, 2200 F, and 2300 F, for any of the as-formed materials. However, the elongation (Figure 3d) for all three types was lower in the 1600 F to 2000 F forming range.

It is of interest to note that the impact energy (Figure 3f) for both the 200 and 250 types increased with increasing temperature from 1900 F to 2300 F, except for a slight drop for the 250 type at 2300 F. Conversely, impact energy declined from 2000 F to 2300 F for the 300 type steel.

As-Formed-Plus-Heat-Treated

As expected, heat treatment resulted in improved mechanical properties with corresponding decrease in impact properties when compared with those of the as-formed material.

Type 200

High velocity deformation with subsequent heat treatment of the 200 series steel increased the 0.1% and 0.2% yield strengths as well as tensile

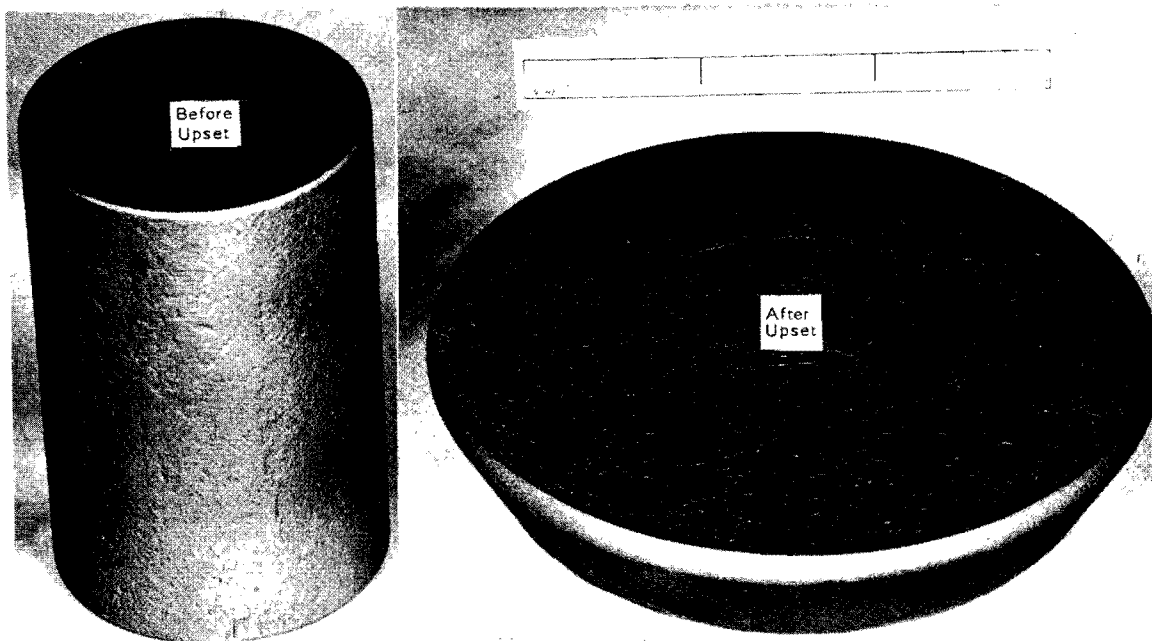


Figure 1. BILLET BEFORE AND AFTER UPSET

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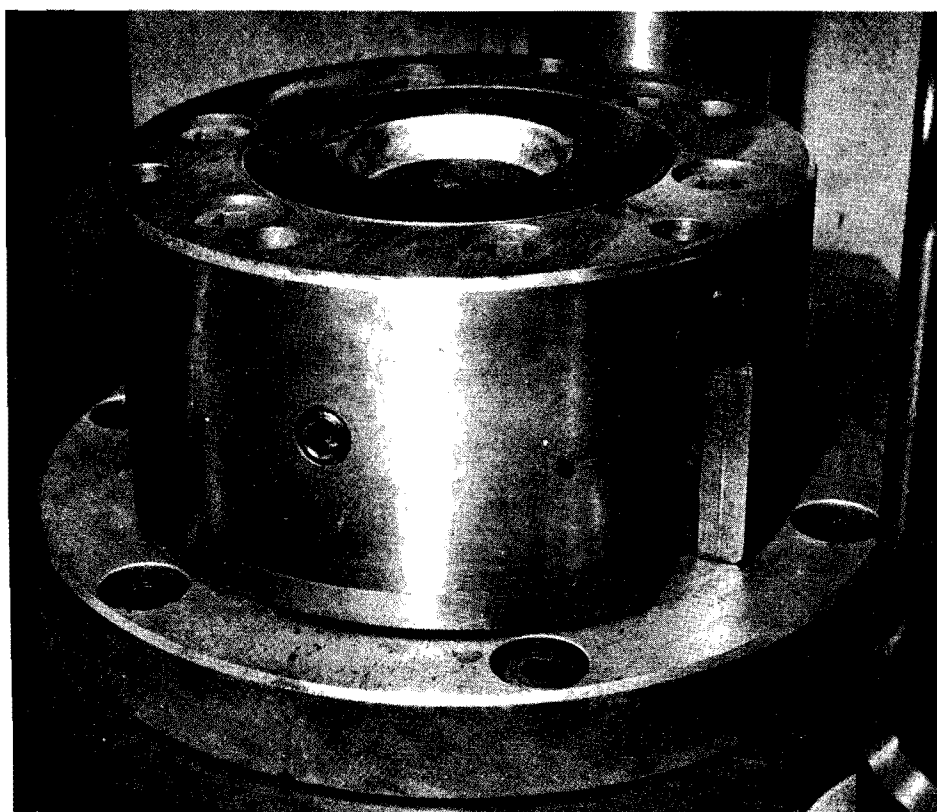


Figure 2. UPSET DIE

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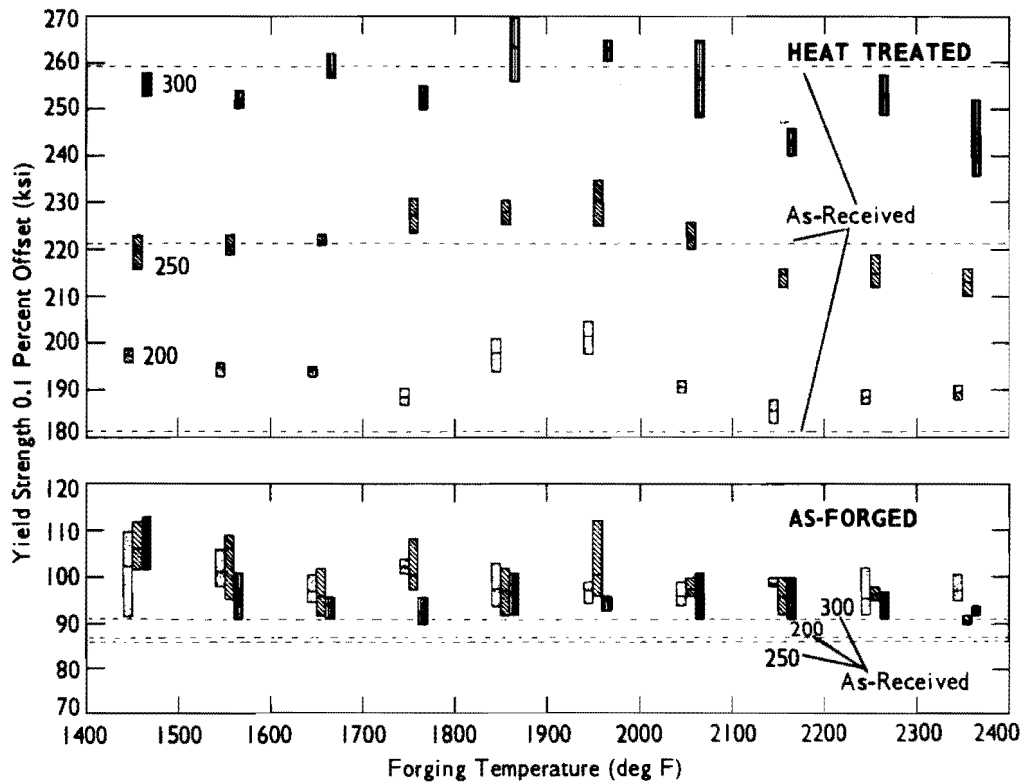


Figure 3a. YIELD STRENGTH AT 0.1 PERCENT OFFSET VERSUS FORGING TEMPERATURE

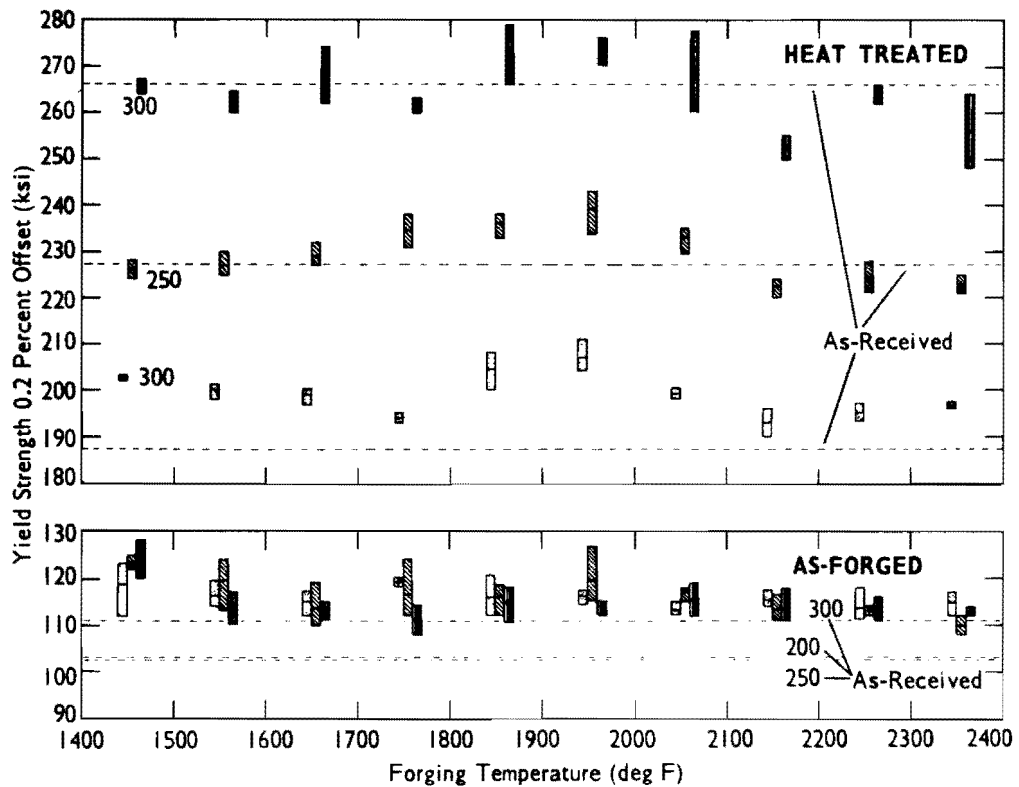


Figure 3b. YIELD STRENGTH AT 0.2 PERCENT OFFSET VERSUS FORGING TEMPERATURE

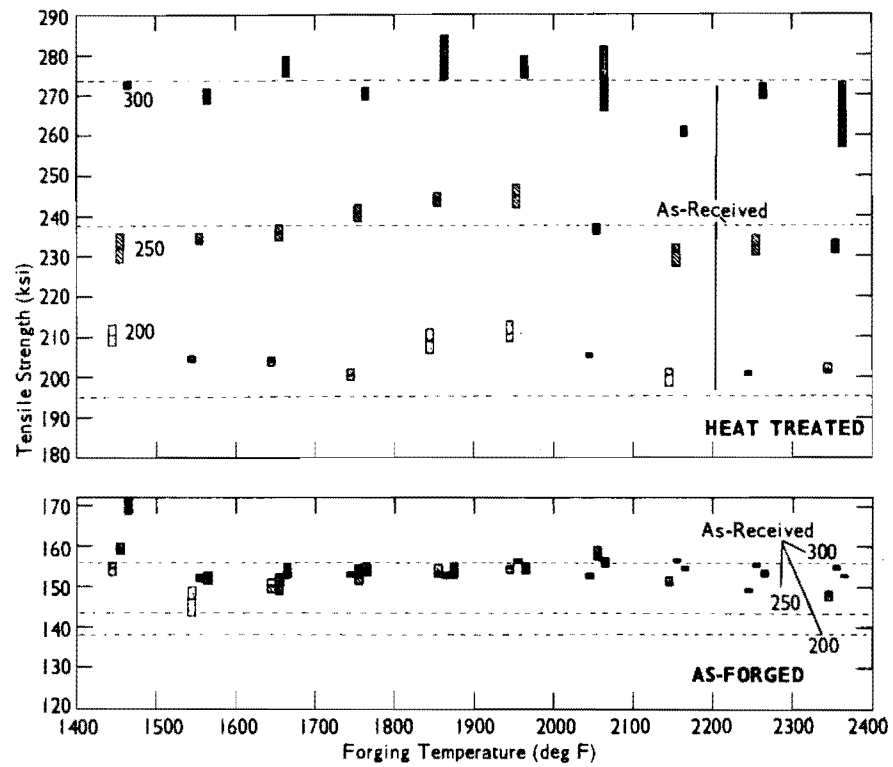


Figure 3c. TENSILE STRENGTH VERSUS FORGING TEMPERATURE

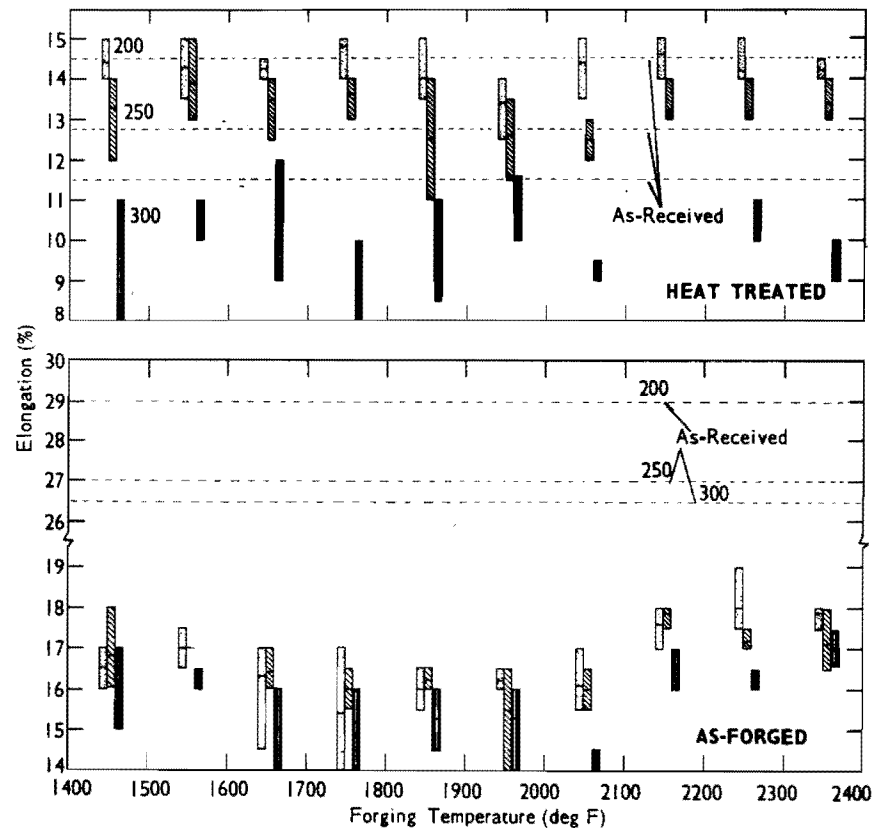


Figure 3d. ELONGATION VERSUS FORGING TEMPERATURE

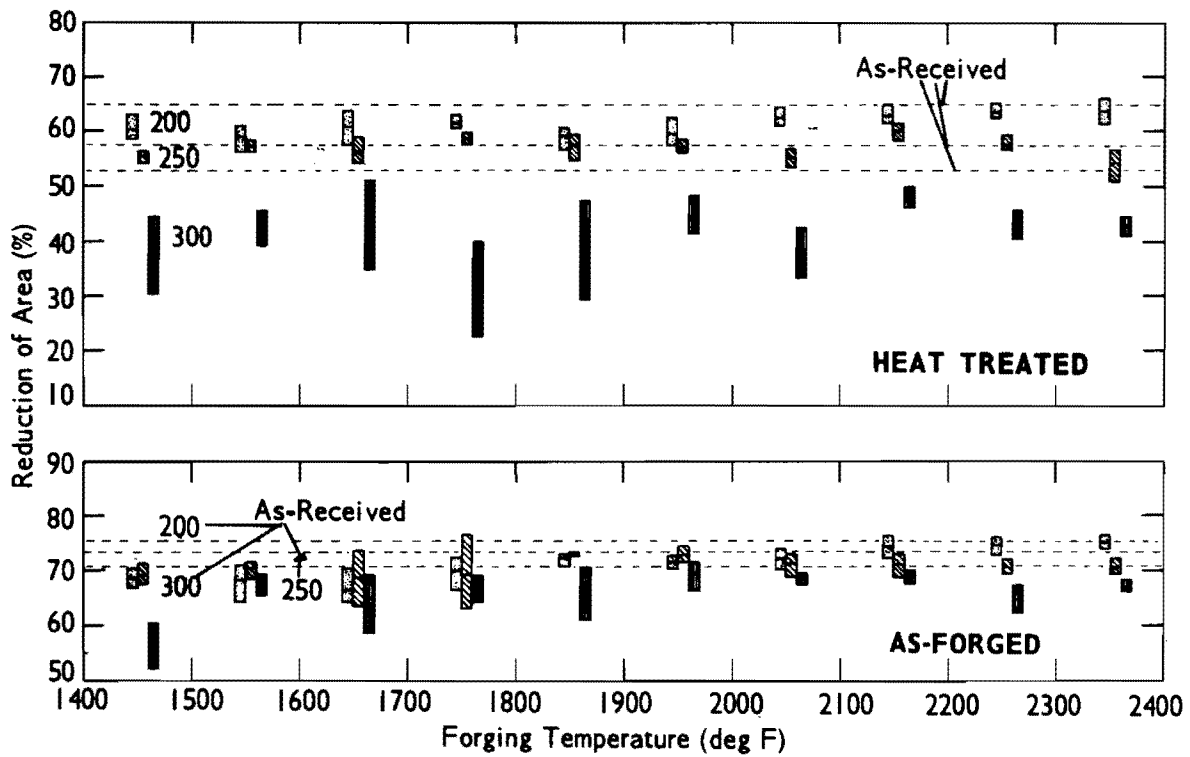


Figure 3e. REDUCTION OF AREA VERSUS FORGING TEMPERATURE

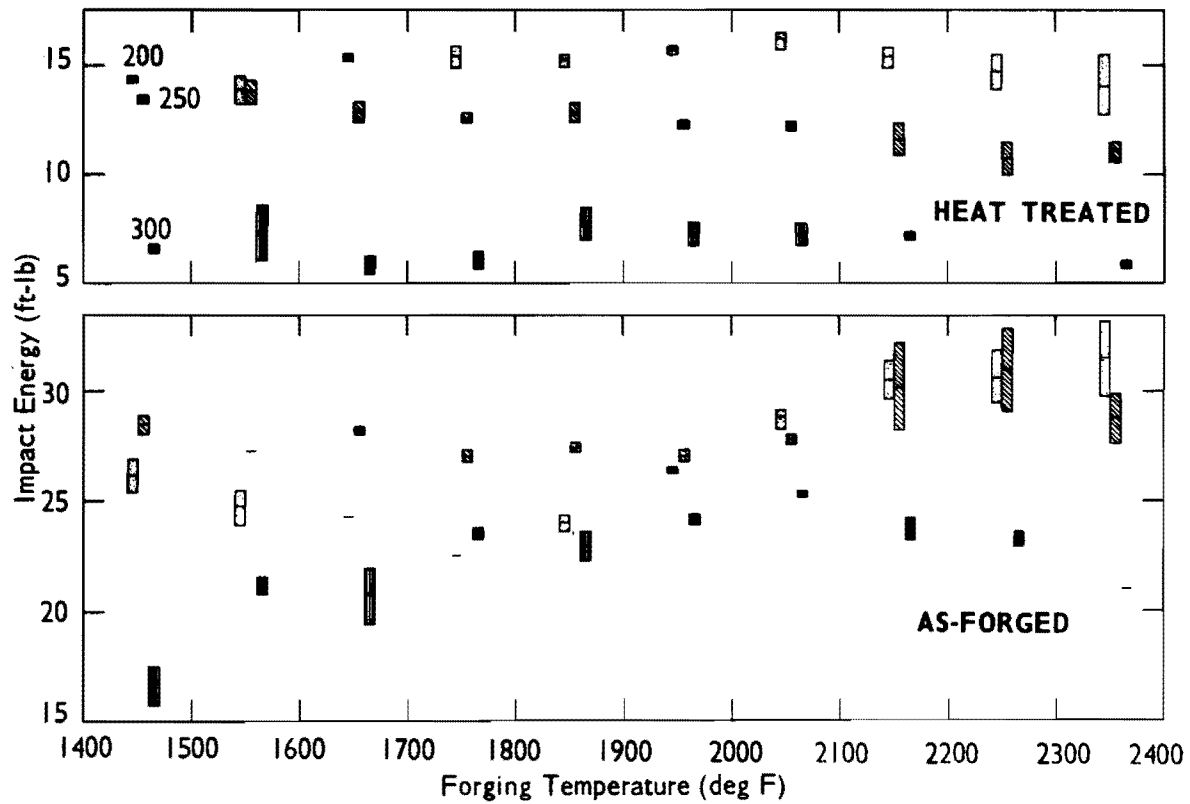


Figure 3f. IMPACT ENERGY VERSUS FORGING TEMPERATURE

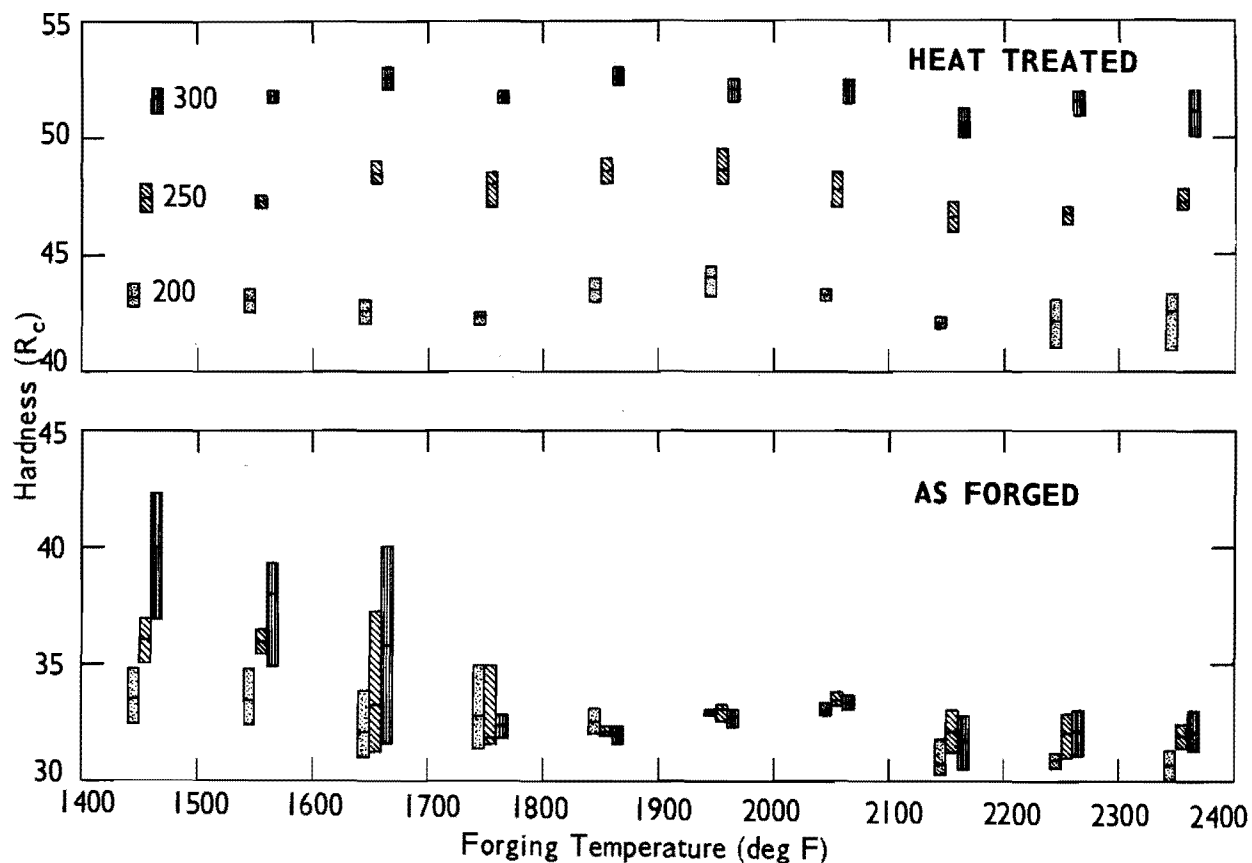


Figure 3g. HARDNESS VERSUS FORGING TEMPERATURE

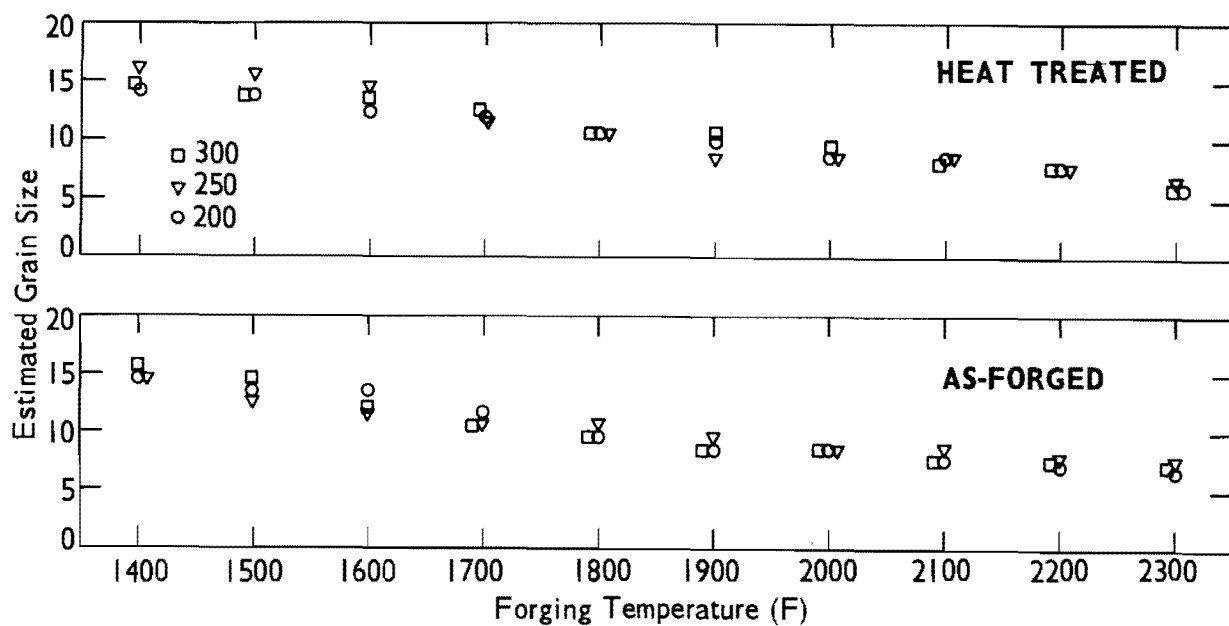


Figure 3h. ESTIMATED GRAIN SIZE VERSUS FORGING TEMPERATURE

strength for all deformation temperatures investigated. When compared with the as-received-plus-heat-treated properties, the maximum gains occurred for material worked at 1900 F and were on the order of 11 percent for the 0.1% yield strength, 10 percent for the 0.2% yield strength, and 8 percent for the tensile strength. Reduction of area and elongation were generally lower for all forming temperatures. Elongation was poorest at the 1700 F deformation temperature.

Type 250

Heat treatment of type 250 maraging steel formed at 1700 F to 2000 F increased the yield strength over the as-received-plus-heat-treated material for both the 0.1% and 0.2% offset, with a maximum increase of approximately 5 percent at 1900 F. Material processed at temperatures of 2100 F to 2300 F with subsequent heat treatment exhibited strength levels below those of the heat-treated-as-received material. Tensile strength was influenced by deformation temperatures, displaying the same trend as the yield strength. Elongation showed a reversed trend with lower values occurring between 1800 F and 2000 F. All other deformation temperatures produced values higher than unworked heat-treated material. Reduction of area did not exhibit any significant trends. No appreciable influence was observed on impact properties as a function of forging temperature.

Type 300

High velocity deformation with subsequent heat treatment of the type 300 steel displayed slightly improved properties over unworked heat-treated material for deformation temperatures of 1800 F to 1900 F for both the 0.1% and 0.2% yield strengths as well as for the tensile strength. Optimum properties were attained by material formed at 1900 F. Neither reduction of area or elongation showed any trend as a function of deformation temperature; in general, both were lower than unworked material for all forging temperatures investigated. Impact properties were not significantly influenced by forging temperature.

Microstructural Examination

Microstructures are shown in Figures 4, 5, and 6. Significant differences between the three types of maraging steel were not evident for the material in the as-forged condition for a deformation temperature of 1400 F (this is below the temperature necessary to induce complete martensitic transformation from austenite on cooling). Heat treatment at 1500 F of the as-forged material worked at 1400 F results in a complete austenite-to-martensite transformation as expected.

Grain boundaries can be seen plainly for the material in the as-forged condition for the 1900 F deformation temperature. The original boundaries are still evident after heat treatment. The precipitation reaction induced by the maraging treatment can also be observed.

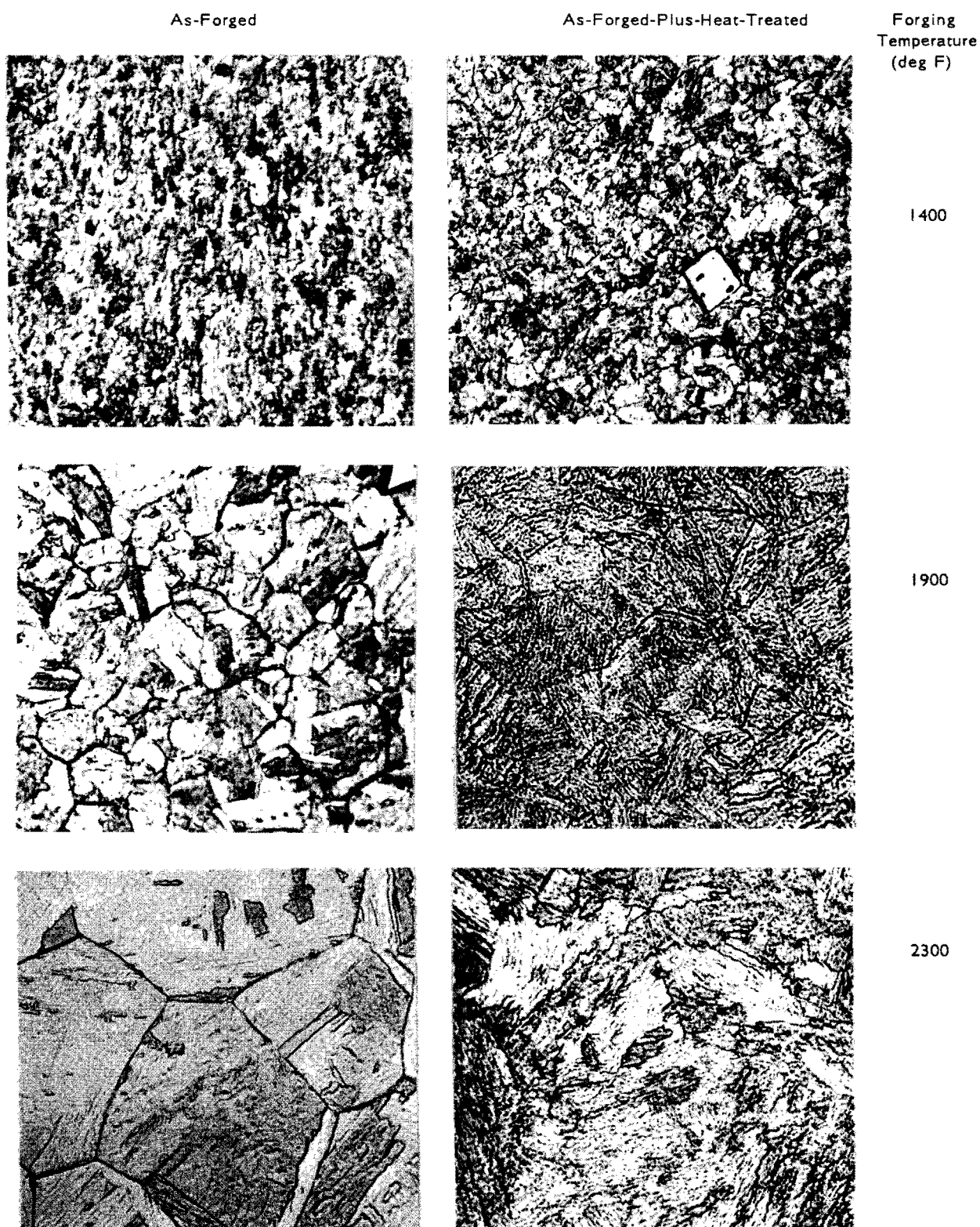
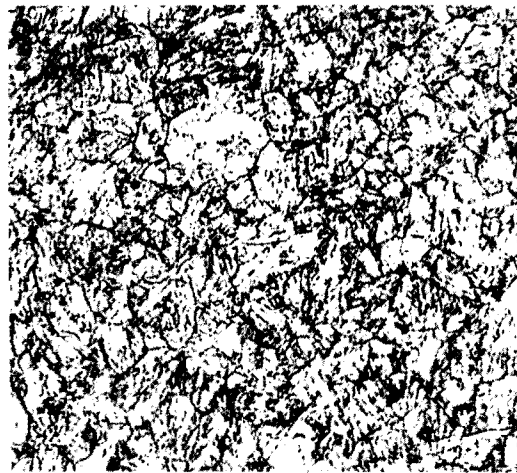
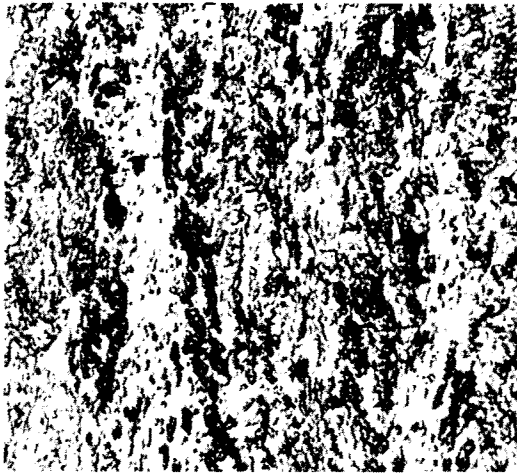


Figure 4. MICROSTRUCTURES OF TYPE 200 MARAGING STEEL
Etch: 150 cc H₂O, 50 cc HCl, 25 cc HNO₃, 1 grain CuCl₂. Mag. 1000X

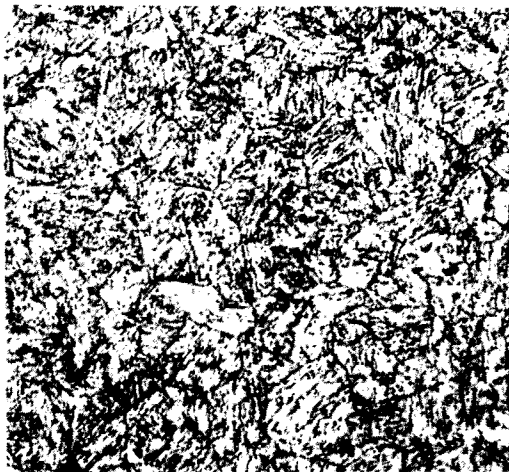
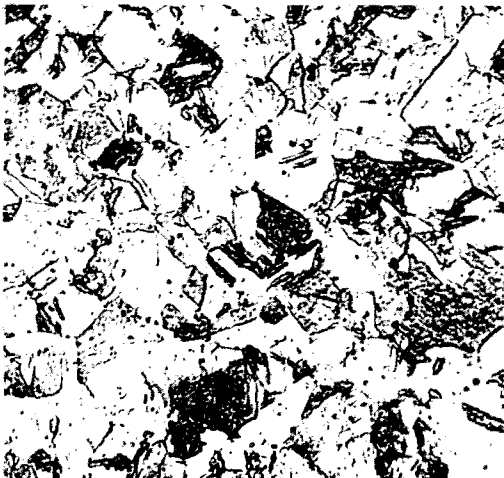
As-Forged

As-Forged and Heat Treated

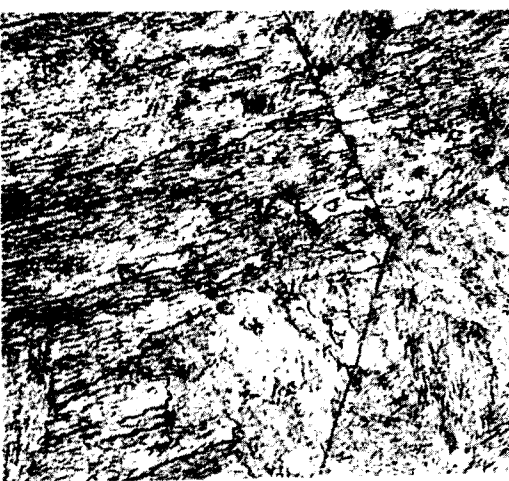
Forging
Temperature
(deg F)



1400



1900



2300

Figure 5. MICROSTRUCTURES OF TYPE 250 MARAGING STEEL
Etch: 150 cc H₂O, 50 cc HCl, 25 cc HNO₃, 1 grain CuCl₂. Mag. 1000X

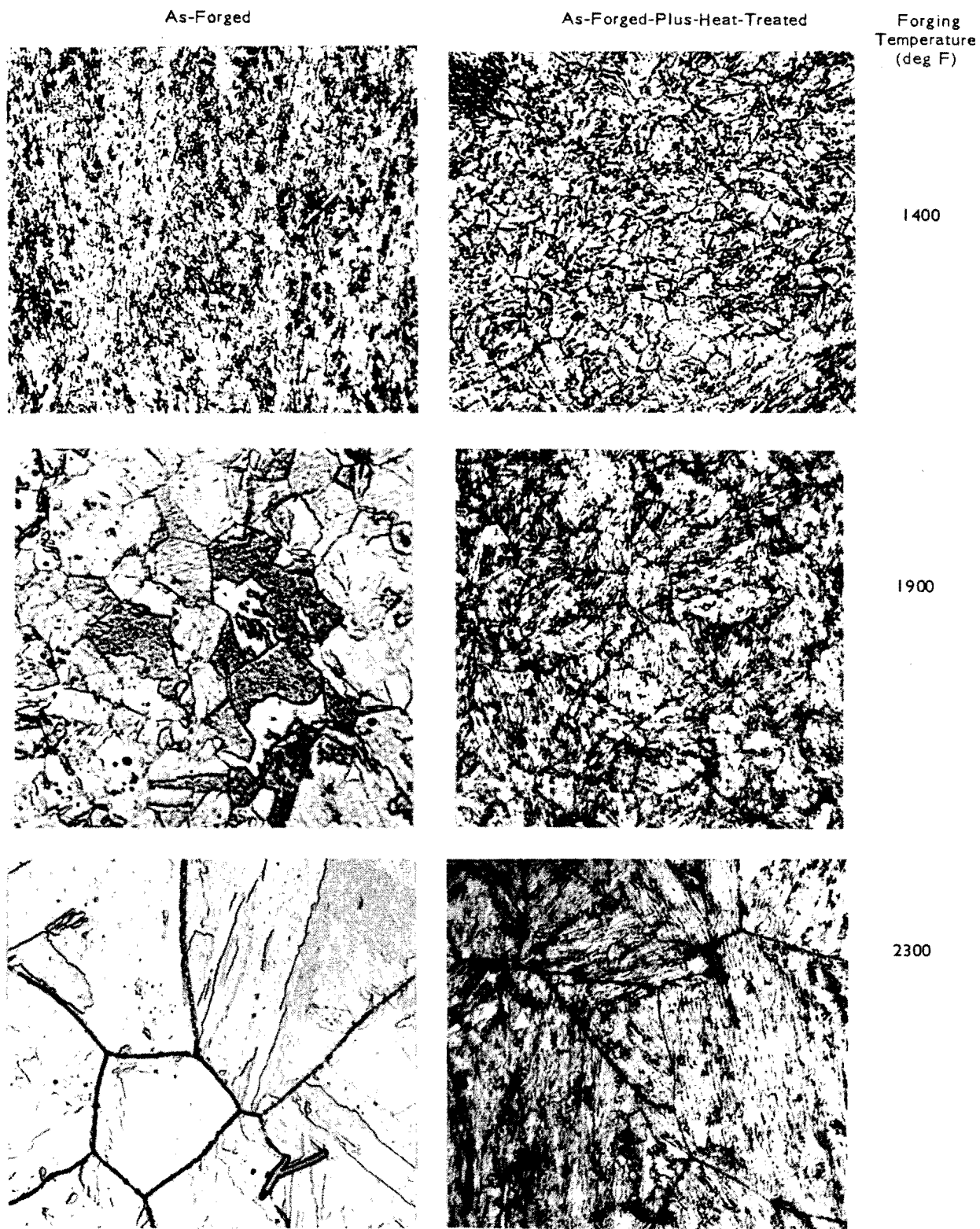


Figure 6. MICROSTRUCTURES OF TYPE 300 MARAGING STEEL
Etch: 150 cc H₂O, 50 cc HCl, 25 cc HNO₃, 1 grain CuCl₂. Mag. 1000X

The structure of the material worked at 2300 F shows substantially larger grains than the material processed at 1900 F and similarly these grain boundaries remain evident after heat treatment. The coarser structures are indicative of the decreased mechanical properties at 2300 F as compared with the 1900 F working temperature.

The estimated grain sizes (Figure 3h) ranged from approximately 14 at the 1400 F forming temperatures to 5 at the 2300 F working temperature. Post heat treatment did not influence grain size.

CONCLUSIONS

In comparing the as-received-plus-heat-treated material with the forged-plus-heat-treated material it was found that:

1. HERF with a pneumatic-mechanical press of types 200, 250, and 300 18% nickel maraging steels did result in slightly improved properties after 75 percent deformation at 1900 F forging temperature.
2. The type 200 steel achieved higher values for both yield and tensile strengths for all forging temperatures when compared with those of the as-received-plus-heat-treated material.
3. Both types 250 and 300 showed decreased yield and tensile strengths when forged at both the low and high end of temperature range investigated. Forgings produced at the mid-range of 1700 F to 2000 F generally resulted in improved properties.

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